Microenvironmental personal and head

Exposure measurements of radio-frequency electromagnetic fields in Melbourne, Australia

Arno Thielens[a,b] , Matthias Van den Bossche[a], Christopher Brzozek[c], Chhavi Raj Bhatt[c], Michael J. Abramson[c], Geza Benke[c], Luc Martens[a], Wout Joseph[a]

[a]Department of Information Technology, Ghent University, Ghent, Belgium

[b]Berkeley Wireless Research Center, Dept. EECS, UC Berkeley, Berkeley, CA, USA

[c]Presee, School of Public Health and Preventive Medicine, Monash University, Melbourne, Australia

Keywords: Personal Exposure; Radio-Frequency Electromagnetic Fields; Head Exposure

Summary

The aim of this study was to simultaneously measure personal radio frequency-electromagnetic fields (RF-EMFs) exposure using two measurement devices. A body-worn personal exposimeter and a head-worn personal distributed exposimeter were used for measuring body and head exposures, respectively, in 15 microenvironments in Melbourne. The summary statistics obtained for total RF-EMF exposure showed a high representativeness ($r^2 > 0.87$ for two paths in the same area). The results obtained during simultaneous measurements using the two devices showed high correlations: $r^2 = 0.94$ for the median along the measured paths).

Introduction

A considerable part of the human population is exposed to Radiofrequency-electromagnetic fields (RF-EMFs), which are used for wireless telecommunication worldwide. This personal exposure to RF-EMFs can be measured using so-called RF personal exposimeters (PEMs) (Bolte et al. 2016). There exist different methods of performing methods using PEMs (Röösli et al., 2010). A microenvironmental exposure assessment study is one of the potential approaches to measure personal RF-EMF exposure in a systematic manner and methods for such studies have been developed and tested in previous studies (Sagar et al., 2016; Bhatt et al. 2016).

Recently, greater research attention has focused on potential cognitive effects of RF-EMF exposure (Roser et al., 2016), which are assumed to relate to RF-EMF exposures to the head. In order to investigate such effects, there is a need to quantify head-specific personal exposure levels. The current and previous generations of PEMs are unable provide head-specific exposure measurements. In a novel approach to measure head exposure to RF-EMF, it has been proposed to integrate and distribute a set of RF-EMF measurement nodes into headgear. Specifically, in this study we have integrated four RF-EMF nodes that measure personal exposure in the 900 DL band into a bicycle helmet (the personal distributed exposimeter or PDE-Helmet), so that it can measure head-specific RF-EMF exposure in the 900 DL band.

In this study, we have simultaneously measured personal exposure to RF-EMFs of the whole body (with body-worn PEMs) and the head (Helmet) across various microenvironments in Melbourne.

Materials and Methods

Studied Micro-environments and Study Design

Fifteen microenvironments were defined in greater Melbourne. The studied microenvironments (see Thielens et al., 2017) have been selected to cover different (sub-)urban activities in the studied area. We considered the following areas (with complementary modes of transport): six residential or sub-urban areas (3 walking, 2 by car, and one on a bicycle), one industrial area (car), three areas dedicated to trade, commerce, business, and tourism in Melbourne's Central Business District (CBD) (walking), three recreational areas (two parks on bicycle and one beach on foot), and two college/university areas (on foot). The selected microenvironments had population densities from 250 inhabitants/km² up to 15000 inhabitants/km².

The measurement study was conducted between 15th November and 22nd December 2016. In each microenvironment, two paths were predefined and followed using one of three different modes of transportation: walking, driving a car, and riding a bicycle. The paths were defined in such a way that it took at least 15 minutes to follow them using the predefined mode of transportation. The measurements were performed during three different timeslots during weekdays: morning (9am – 12noon), midday (12noon – 3pm), and afternoon (3pm – 6pm). Each of the 30 studied paths were repeated five times, once on each day of the week, and was executed twice in two different timeslots and once in the remaining third timeslot, resulting in 15 × 2 × 5 = 150 measurements along predefined paths.

Three microenvironments (six paths) were considered to be suitable to measure using a bicycle: two parks and one suburban area, where every path was repeated four times (24 measurements). The researchers' wireless devices such as mobile phones were in flight mode, eliminating any contribution to RF-EMF exposure.

Measurement devices

Two measurement devices were used in this study: one or two Expom-RF devices worn on both hips and the PDE-Helmet (see Fig. 1), which was worn on the head during bicycle measurements only. The ExpoM-RF is a PEM (http://www.fieldsatwork.ch), which measures electric field strengths in 16 different frequency bands every 4 s. The PDE-Helmet is a measurement device developed at Ghent University (Thielens et al., 2016, 2017) that uses four RF nodes distributed over the head, in order to reduce the measurement uncertainty on the incident RF power density. The device measures incident electric fields on the head of a subject with a frequency of 1 Hz in the 900 DL band (920-960 MHz). The detection range of the PDE-Helmet (with on-body calibration) was 11.3 mV/m – 113 V/m.

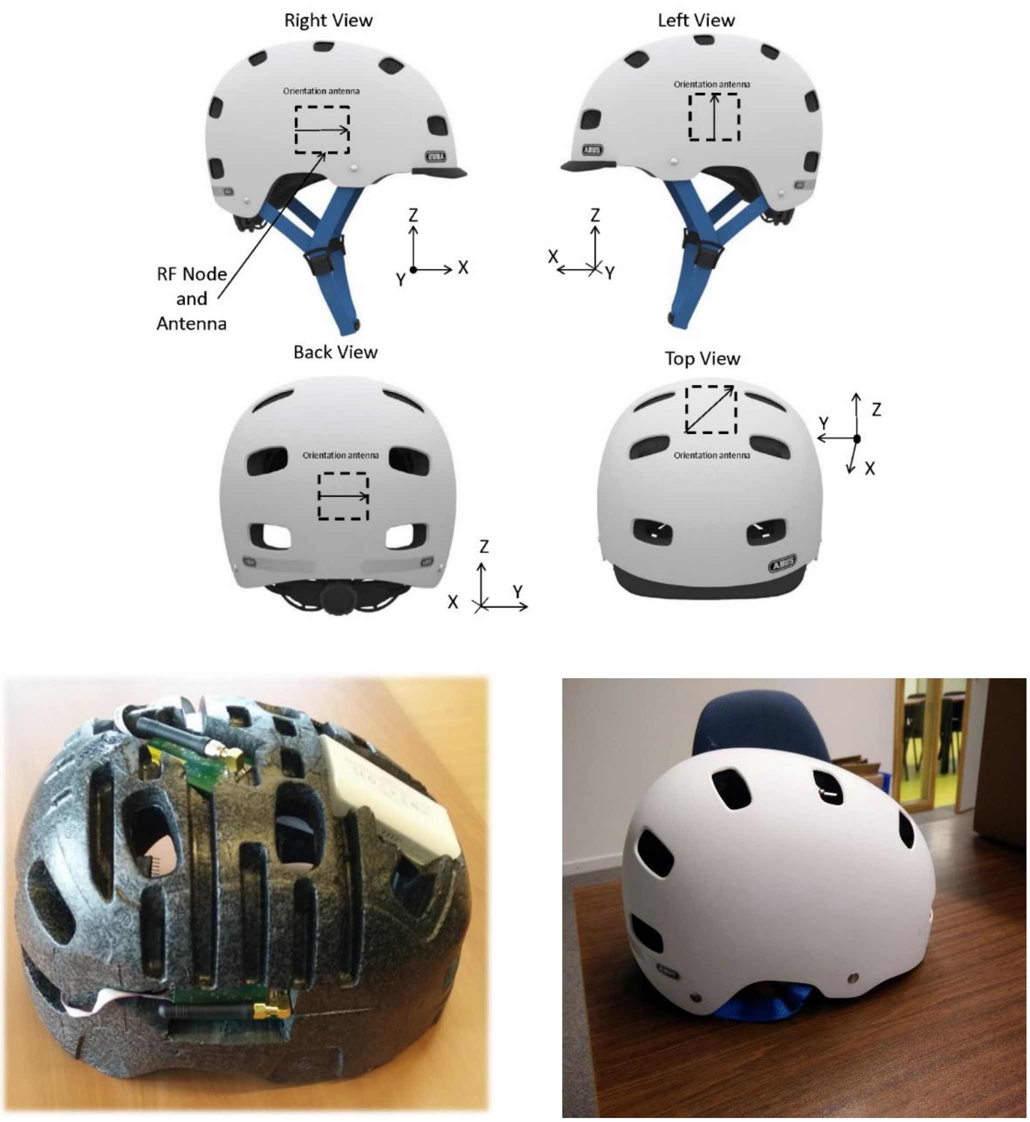

Figure 1. The PDE-Helmet. The locations of the antennas inside the helmet are shown on top. The interior of the helmet showing the padding in black, the folded stub antennas with receiver nodes in green-black-gold, and the battery in white, are shown on the bottom left. The device in its final form-factor is shown on the bottom right.

Data processing

Electric field strength values registered by the devices were processed using Matlab (Mathworks, MA, USA). The values falling below the lower limit of detection (LOD) were replaced by LOD/√2. There were no data higher than the upper limit of detection. All electric field (E) values were converted to power density values in each frequency band. During measurements where two ExpoM-RF devices were used simultaneously by the same researcher, geometric means of the power density obtained with the two ExpoM-RFs were considered. The power densities were processed to determine the total RF-EMF exposure, which is defined as the sum of all measured power densities in each frequency band at each time instance. The measured power densities in the 900 DL band using both devices were processed as well. For both quantities, we calculated the 16th, 50th, 84th and 95th percentiles, the arithmetic average, and the geometric average along each path. We calculated these statistics on the pooled data for the separate paths and the pooled data for all repetitions along all paths in each microenvironment. In order to compare measurement results obtained with the two types of measurement devices, namely the PDE-Helmet and the (pair of) ExpoM-RF(s), we compared correlations of the summary statistics obtained with different measurement devices obtained during simultaneous use of both devices. We compared the summary statistics obtained from the PDE-Helmet with those obtained using (a pair of) simultaneously worn ExpoM-RF(s).

Results and Discussion

Table 1. *Summary statistics of E_{rms} using the ExpoM-RFs in 15 microenvironments in Melbourne.*

E_{rms} (V/m)	Total					
	μ	std	p_{16}	p_{50}	p_{84}	p_{95}
Microenvironment						
Park 1	**0.39**	0.51	0.09	0.22	0.53	0.83
Park 2	**0.53**	0.75	0.17	0.34	0.66	1.03
CBD 1	**0.89**	1.07	0.36	0.64	1.17	1.66
University Campus 1	**0.57**	0.86	0.11	0.27	0.74	1.22
CBD 2	**0.79**	0.89	0.34	0.60	1.05	1.46
CBD 3	**0.72**	0.88	0.31	0.53	0.93	1.36
Industrial Area	**0.09**	0.1	0.06	0.08	0.11	0.15
Beach	**0.21**	0.25	0.09	0.14	0.26	0.42
Suburban Area 1	**0.36**	0.62	0.04	0.09	0.39	0.83
University Campus 2	**0.43**	0.64	0.13	0.27	0.54	0.81
Suburban Area 2	**0.23**	0.47	0.04	0.06	0.16	0.47
Suburban Area 3	**0.25**	0.41	0.05	0.12	0.28	0.52
Suburban Area 4	**0.05**	0.04	0.03	0.05	0.06	0.07
Suburban Area 5	**0.06**	0.06	0.04	0.06	0.08	0.10
Suburban Area 6	**0.12**	0.2	0.03	0.05	0.15	0.26

[a] Six quantities are listed: the mean (μ), the standard deviation on the mean (std) and four percentiles the 16th , 50th , 84th, and 95th percentiles, indicated by p_{16}, p_{50}, p_{84}, and p_{95}, respectively.

Table 2 shows the summary statistics per microenvironment for ‘Total’ RF-EMF exposures measured with ExpoM-RFs. The area with the highest ‘Total’ average exposure (0.89$\pm$1.07 V/m) was CBD 1. The other areas in the CBD: CBD 2 (0.79$\pm$0.89 V/m) and CBD 3 (0.72$\pm$0.88 V/m), ranked 2nd and 3rd in highest ‘Total’ average exposure. The lowest average ‘Total’ average exposure was measured in the less populated suburban and industrial areas: the industrial area (0.09$\pm$0.1 V/m), suburban area 4 (0.05$\pm$0.04 V/m), suburban area 5 (0.06$\pm$0.06 V/m), and suburban area 6 (0.12$\pm$0.2 V/m). Most of the ‘Total’ RF-EMF exposure was attributed to DL RF-EMF signals. We observed variations according to type of microenvironment. The areas in the CBD were those with the highest total RF-EMF. The CBD has a high population, RF-EMF-user, and RF source density. A lower total RF-EMF exposure was observed in the sub-urban areas with lower population density than those areas in the CBD.

We found high spearman correlations between the summary statistics of total obtained along both paths: r^2 = 0.90, 0.93, 0.95, 0.87, and 0.87, for the mean, the 16th, 50th, 84^{th}, and 95th percentiles, respectively. Indicating that path selection within the microenvironments was less critical. These findings are in line with those published by Sagar et al. (2016) and Bhatt et al. (2016) that found high correlations r = 0.9 and r = 0.74, respectively, were found for total exposure on two repetitions of the same path.

Twenty four simultaneous measurements using both the PDE-Helmet and either one or two ExpoMs-RF were conducted. Summary statistics were determined for the 24 measurements and correlated. These are shown in Figure 2.

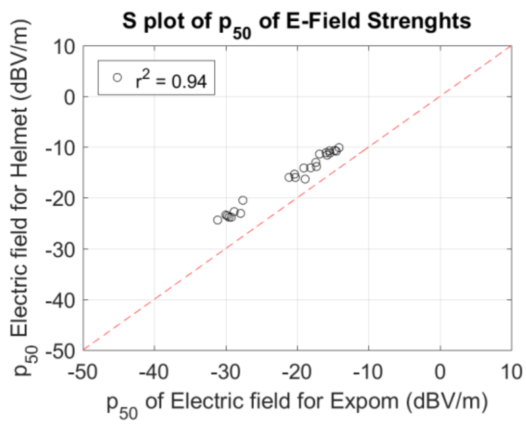

Figure 2: *Scatterplot of the median of the Electric Field Strength in the 900 DL band. Measured using body-worn ExpoM-RFs (horizontal axis) and the PDE-Helmet (vertical axis) in 3 preselected microenvironments in which 2 paths are repeated 4 times.*

The median values measured using the PDE-Helmet were in between 0.06 V/m and 0.31 V/m. We obtained very high correlations between both measurement devices, up to r^2 = 0.94 for the median values. The measurements using the PDE-Helmet were approximately 5 dB higher than those obtained using the ExpoM-RF(s). Bhatt et al. (2016) found an underestimation of 6-7 dB for the ExpoM-RFs. Aminzadeh et al. (2017) found 5 dB underestimation in the 900 DL band for two commercial PEMs: the ExpoM-RF and the EME SPY, respectively, in line with our results.

Conclusions

This study showed variations of personal total RF-EMF exposure depending on the considered microenvironment within Melbourne. The summary statistics obtained from measurements along paths in 15 microenvironments showed high correlations with those obtained from measurements along another path in the same environments, indicating representativeness of the selection of paths within the chosen microenvironments for the total RF-EMF exposure. The results obtained during simultaneous measurement using the PDE-Helmet and the ExpoM-RF show high correlations, which serve as a validation of the measurement devices.

References

Aminzadeh, et al. 2018. Sensors 18(1):272.

Bhatt, et al. 2016. Environmental Research 151: 547–563.

Bolte, J.F.B. 2016. Environment International 94: 724-735

Röösli, et al. 2010. Environ Health. 9, 23, 1–14.

Roser K, et al. 2016. International journal of public health 2016: 9 pages.

Sagar, et al., 2016. Environ. Res 150,289–298.

Thielens, et al. 2018. Environmental Research 162: 81-96.